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Department of Psychology

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Joyce H. Iavecchia
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and
Stanley N. Roscoe

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In two experiments the apparent size of a simulated horizon moon was measured as a function of the distribution of texture in the natural vistas against which it appeared. Size was found to increase as the distance to the dominant textural stimulus to accommodation increased and to decrease as the moon rose above the plane of surface texture. In the second experiment, the subjects' accommodation distances to the various scenes were also measured with a laser optometer, and after appropriate transformations, the size judgments were found to correlate .89 with the measured accommodation values, thereby suggesting that the fabled moon illusion is mediated by the oculomotor adjustments of visual accommodation.

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PROBLEM

The cause of the moon illusion has remained a mystery despite countless experiments and pseudo explanations. The common lay belief that the larger apparent size of the moon when just above the horizon is caused by atmospheric magnification is clearly incorrect, as shown by comparing photographs of the moon at different elevations. The zenith moon in fact subtends a slightly larger visual angle than the horizon moon because it is nearer to the observer by the distance of the earth's radius, approximately 4000 miles.

In essence, two schools of scientific thought have evolved, one explanation based on neuromuscular causes and the other on perceptual causes. Neuromuscular determinants have been studied by Schur (1925), Holway and Boring (1940), Hermans (1954), and Wood, Zinkus, and Mountjoy (1968), among others who have attributed the illusion to changes in vestibular stimulation due to head and eye elevation. On the other hand, Kaufman and Rock (1962) found evidence from a series of experiments that appears to invalidate the neuromuscular theory.

Kaufman and Rock went beyond this refutation to reinvoke Ptolemy's explanation of the moon illusion that apparent size depends upon apparent distance (Boring, 1942). This hypothesis begins with the assumption that the horizon looks farther away than the zenith of the celestial vault. Kaufman and Rock's subjects reported this assumption to be correct; thereby supporting the explanation that perception of the horizon as farther makes the horizon moon appear farther and, because the visual angle remains unchanged, larger.

Kaufman and Rock's conclusion that the horizon moon looks larger because it appears farther away follows from the size-distance invariance hypothesis that perceived size and distance covary, a rule with many exceptions. Never-

theless, this explanation has been criticized because observers generally report that the horizon moon appears closer as well as larger than the zenith moon. This is an example of the size-distance paradox. Roscoe (1977) suggests that Kaufman and Rock's explanation might be close to the truth if "distance of accommodation" were substituted for their "registered distance." In other words, Roscoe hypothesizes that the horizon moon looks larger because the eye accommodates to a farther distance than it does to the zenith moon.

Kaufman and Rock also studied the role of terrain in determining the magnitude of the moon illusion and found this variable to have important effects. Their investigations showed that, as more distant terrain becomes visible, the impression of distance increases, and the moon appears larger. Similarly, if the moon is framed between buildings, as is frequently found in the city, it appears larger yet. On the other hand, when a scene is inverted, the impression of distance decreases, and the apparent size of the horizon moon is reduced.

Fitting this idea to Roscoe's hypothesis, the functional myopias -- night, empty field, and instrument -- can be considered as instances in which there is reduced texture in the visible field. Functionally myopic subjects judging the size of a horizon moon would be expected to perceive the moon as smaller since their eyes would actually be focused at a distance much nearer than the horizon. Accommodation to the near field would result in things appearing smaller and farther away (Roscoe, Olzak, and Randle, 1976; Biersdorf and Baird, 1966; Ohwaki, 1955).

However, a perfect agreement among subjects on the apparent size of the moon in various settings would not be expected. As Leibowitz and Owens (1975) have shown, the magnitude of the functional myopias is different for different people depending on their particular dark focus or resting accommodation distance. Moreover, the distribution of resting accommodation values

for their 124 subjects was gaussian if expressed in diopters and positively skewed if expressed in terms of distance, with a mean of about two feet and a range from ten inches to 20 feet or more.

Functional myopia is maladaptive in that it degrades the retinal image and focuses the eyes near even when objects of interest are at a distance. Mandelbaum (1960) noted that when one stands at a particular distance from a screen, later shown by Owens (in press) to coincide with the dark focus, objects beyond the screen are out of focus. A screen at dark-focus distance from the observer's eyes acts as a powerful accommodation "trap." Consider the fighter pilot with a scratched windshield and with a resting accommodation equal to the distance between his eyes and the windshield. Myopic accommodative responses would be dangerous in this situation.

Similarly, too weak a refraction or even a negative refractive state could be maladaptive. Consider the pilot landing at night over water toward a brightly lighted airport and city in the background. On looking out, the pilot sees a large black field of water below a thin horizontal band of tiny individual lights in the distance. If the pilot accommodates to the far lights, he would judge them to be larger and nearer and to extend lower in his visual field than they would appear on a clear day. Consequently, he might undershoot his aimpoint and land in the water as happened in several accidents during the 1960s.

Changes in size and distance perception associated with accommodative shifts imply that the horizon moon would appear large when the only effective stimulus to accommodation is its reflection off the water or terrain far away. Also, the horizon moon or sun would be expected to appear large during the day if an empty or textureless visual field lies between the observer and some distant stimulus to accommodation. This situation can be experimentally

constructed by masking texture in a visual scene at near and intermediate distances, thereby permitting visibility of texture only at far distances.

From the preceding considerations, the following experimental questions are raised relative to the moon illusion. What is the effect of masking the view of different portions of texture in the visual scene -- near, intermediate, or far -- between the observer and the horizon moon? What is the effect of varying the amount of empty field between the observer and the nearest visible texture in the visual field as occurs when looking out windows on different floors of a tall building? Are shifts in the distance of accommodation accompanied by corresponding shifts in size judgments? Finally, what is the relationship between an individual's resting accommodation and the effects of the distribution of texture on the moon illusion?

METHOD

Apparatus

To investigate the experimental questions, an apparatus similar to that developed by Kaufman and Rock was used (Figure 1). A lighted disc subtending approximately 0.5°, as does the sun or moon, was superposed on chosen visual scenes. Specifically, a collimated disc of light was projected onto a combining glass to appear as a virtual image at optical infinity. This method of presentation has the potential for "pulling" accommodation to distances other than the dark focus depending on the particular distribution of texture in the visual field.

A second lighted disc, an uncollimated comparison "moon," was viewed directly by lowering a first surface mirror into the line of sight. The subject adjusted its diameter by rotating a knob that controlled an iris. The comparison disc was at one meter from the eye but in an otherwise dark field without readily determined cues to actual distance. Thus, the eye was allowed to relax toward its dark focus. The subject's task was to adjust the diameter of the comparison disc to match the apparent size of the standard or collimated disc projected onto the outside visual scene.

Two experiments using this apparatus were conducted. The first experiment varied elevation of the subject's point of view from the third through the eighth floors of a building. Whether the dominant stimulus to accommodation in the scene were near or far from the subject's eye was thereby varied concomitantly. In the second experiment, masks were used to occlude selected portions of the subject's field of view. They were inserted into the apparatus normal to the line of sight between the first surface mirror and the combining glass. Thus, the masks were not visible while the comparison disc was visible.

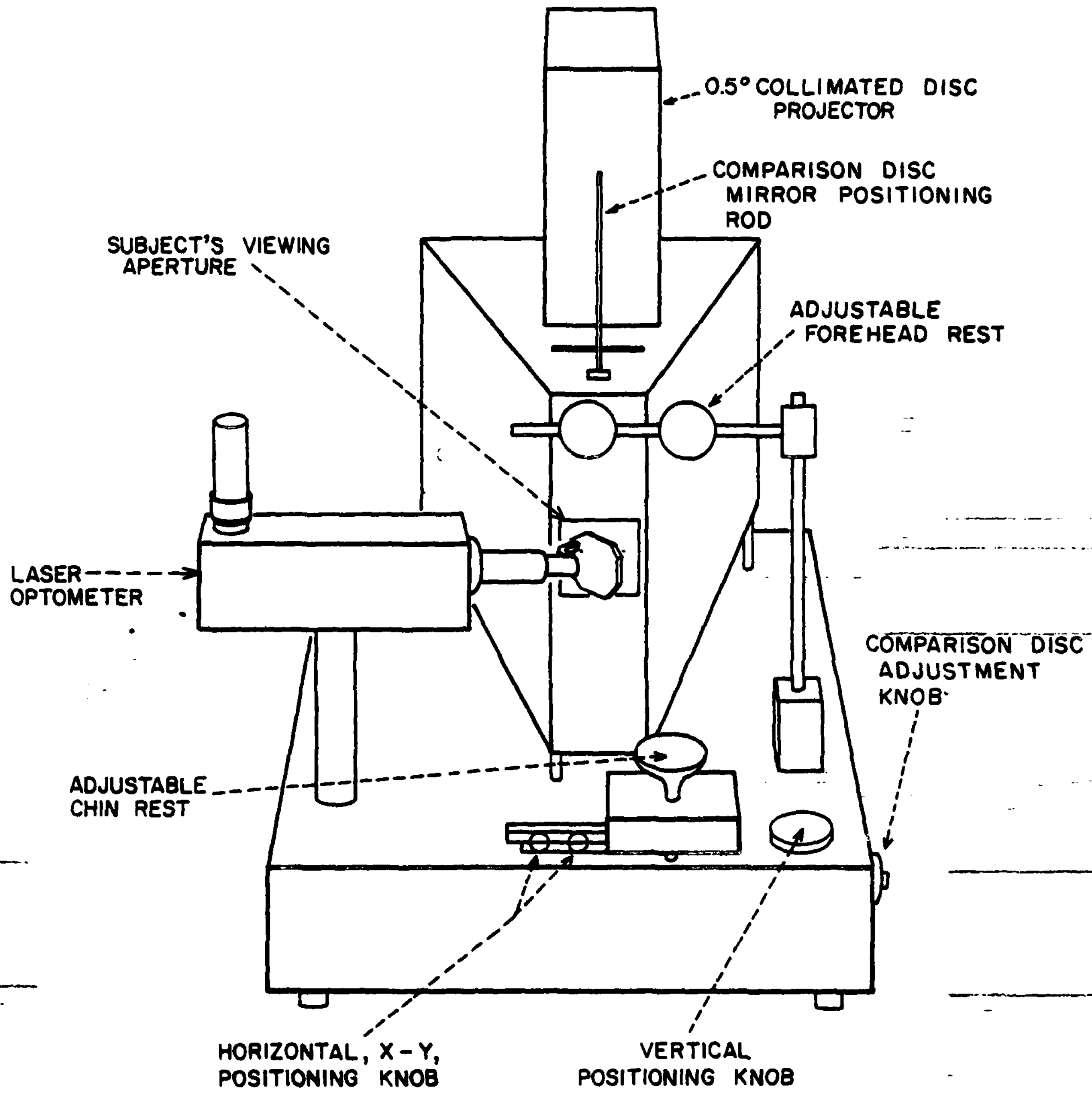

Figure 1. Illustration of the moon-size-matching apparatus with laser optometer in position.

In the second experiment, the subjects' visual accommodation distances were measured with a laser optometer (Leibowitz and Hennessy, 1975) in addition to their judgments of the apparent size of the collimated "moon." Laser light was reflected from a rotating drum to produce a red speckle pattern that was superposed on the moon. The speckles would appear to flow upward or downward, respectively, if the subjects' eyes were accommodated to a nearer or farther optical distance than the drum from the projection lens of the optometer. The speckle pattern would be presented for one second, following which a subject would report the direction of apparent flow; the experimenter would adjust the position of the drum accordingly until the subject reported a nondirectional "swirling" or "boiling" of the speckles.

Design

In both experiments, variables of interest were treated as within-subject factors because of the tremendous variance among subjects on perceptual judgments and visual accommodation distances.

Experiment I. The variables were (1) viewpoint elevation, from six different floors of a building, (2) three different directions of view from each floor, and (3) a procedural variable, ascending and descending adjustments of the size of the comparison disc. Height above the ground increased or decreased the amount of empty space between the observer and some texture in the distance. This variable was manipulated by looking through corresponding windows from the third through the eighth floors of the Psychology building at the Urbana-Champaign campus of the University of Illinois. Judgments were made when the collimated disc was projected toward the center view from each window and also at specific angles left and right of center. For comparative purposes, a newspaper was placed one meter from the subject's eye position, and size judgments also were made of the collimated disc pro-

jected onto it. The newspaper served as a near accommodation stimulus or "trap."

Experiment II. Four masks were used to reveal horizontal bands of texture in the lower half of the visual field at Near, Intermediate, Far, and Very Far distances from the observer. A fifth mask obscured all of the textured visual field below the horizon. A sixth, fully transparent "mask" served as a control condition. Once again ascending and descending adjustments of the size of the comparison disc were called for. Experiment II was conducted on the sixth floor, using only the center view through the window.

Subjects

Subjects for the experiments were graduate students in psychology. Their uncorrected left eye acuity was normal or better at both 10 and 20 feet. All subjects were in their twenties or thirties to limit the effects of age on accommodative range.

Procedures

Initially, the brightness of the standard disc was set according to the illumination of the day. Then the brightness of the comparison disc was matched to the standard. Subjects wore a patch over the right eye so that judgments were monocular. Also, subjects wore a hood over the head and shoulders to eliminate competing reflections in the apparatus and to minimize the amount of room illumination entering the eye. Adjustable forehead and chin rests were used because head movements alter the position of the collimated disc in the visual scene. A special mask was used to guide subjects in adjusting eye position so that both standard and comparison discs appeared in the same position, with the center of the standard disc always 1/2-degree above the horizontal and laterally centered in the field of view.

Each subject began by making three practice judgments to familiarize himself or herself with the task and with the dynamics of the control that

adjusted the size of the comparison disc. The lever that controlled the sequential exposure of the two discs was moved up and down by the experimenter at three-second intervals. A subject was allowed two, three, or four comparisons of the sizes of the two discs, depending on the number of adjustments each required to be satisfied that the sizes agreed during practice.

Six size judgments were made under each textural condition. Three of each set of six were made as ascending adjustments of the comparison disc from an initially small diameter and three as descending adjustments from an initially large diameter. During experiment two, size judgments were preceded by an accommodation measurement to each of the masked outside scenes and followed by an accommodation reading for the comparison disc set at a diameter equal to that of the sixth size adjustment made by the subject. A second accommodation measure was then taken to the particular outside scene.

Additionally, two dark-focus measurements were taken before and two after the experimental judgments. A black hood was placed over the entire viewing apparatus so that outside illumination was excluded and the first-surface mirror was lowered into the comparison-judgment position but with the comparison moon not illuminated. Finally, six size judgments and two accommodation measurements were taken of the collimated moon presented in darkness without cues to distance.

RESULTS OF EXPERIMENT I

Moon size ratios were computed based on the apparent size of the moon projected onto the newspaper as a unity value. Thus, the size ratios represent how much larger in diameter a horizon moon in a particular view on a particular floor appears relative to a moon projected onto a newspaper at one meter. The ratios obtained by this procedure are similar to the Kaufman and Rock ratios that related the apparent size of the horizon moon to a zenith moon.

Mean size ratios from the third through the eighth floor were 1.12, 1.20, 1.25, 1.30, 1.27, and 1.23, respectively (See Table 1 and Figure 2). These means differed reliably ($\underline{F} = 2.5$, $\underline{df} = 5/25$, $\underline{p} < .05$) and are consistent with those obtained by Kaufman and Rock with similar background textures. As the moon was projected against increasingly distant surfaces from the third through the sixth floors, its apparent size increased monotonically. From the sixth floor view, the moon was projected against the sky just above the most distant surface texture. From the seventh and eighth floors, the moon was projected against the sky higher and higher above the horizon.

The mean size ratios for the left, center, and right views of the campus were 1.24, 1.22, and 1.23. These ratios were reliably different from the unity value of the moon projected onto the newspaper ($\underline{F} = 14.3$, $\underline{df} = 3/15$, $\underline{p} < .0001$), but ratios for the three views did not differ reliably from one another ($\underline{F} = 0.2$, $\underline{df} = 2/10$, $\underline{p} < .8$). In other words, a near accommodation stimulus resulted in a smaller apparent moon size than did the textured background scenes with good distance cues visible through the window. Judgments of the moon projected on the newspaper were quite consistent from floor to floor, as they should be. Judgments for ascending and descending adjustments of the comparison moon did not differ reliably. Also, no interaction effect was reliable.

A second set of moon size ratios was based on the mean apparent size of the moon on the sixth floor as a unity value. These size ratios represent how much smaller a horizon moon appeared in a particular view on a particular floor relative to the largest apparent size observed for the horizon moon. Mean size ratios from the third through the eighth floor then were 0.86, 0.93, 0.97, (1.00), 0.98, and 0.95, respectively (Table 2). The difference between the two ratio bases illustrates the question of whether the moon illusion is the increase in perceived size of the horizon moon under certain textural conditions, or, conversely, an apparent size shrinkage with reduction in distant accommodation stimuli.

TABLE 1

Apparent Size of the "Moon" for Left, Center, and Right Views from Each Floor, Expressed Relative to its Apparent Size when Projected onto a Newspaper at One Meter.

	View			
Floor	Left	Center	Right	$\bar{Y}$ Floor
3rd	1.15	1.11	1.09	1.12
4th	1.22	1.18	1.21	1.20
5th	1.25	1.24	1.27	1.25
6th	1.29	1.30	1.30	1.30
7th	1.30	1.22	1.28	1.27
8th	1.22	1.27	1.21	1.23
$\bar{Y}$ View	1.24	1.22	1.23	

TABLE 2

Apparent Size of the "Moon" when Viewed from Different Floors, Expressed as a Ratio of its "Size" from the Sixth Floor View and as a Ratio of its "Size" when Projected onto a Newspaper at One Meter.

	RATIO BASE	
Floor	6th floor view	Newspaper
3rd	0.86	1.12
4th	0.93	1.20
5th	0.97	1.25
6th	(1.00)	1.30
7th	0.98	1.27
8th	0.95	1.23
Newspaper	0.77	(1.00)

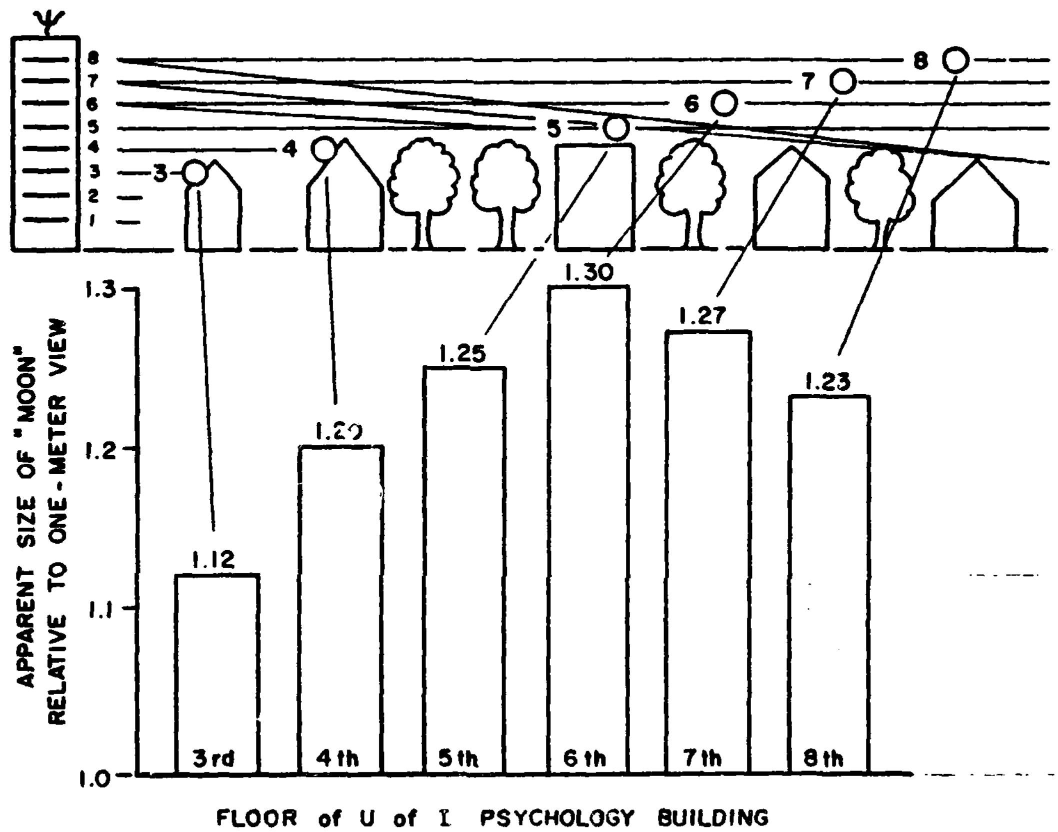

Figure 2. Apparent size of the moon when viewed from different floors of the Psychology building, expressed as a ratio of its size when projected onto a newspaper at one meter.

DISCUSSION OF EXPERIMENT I

Results suggest that distance of accommodation may explain the changes in the apparent size of the moon historically referred to as "the moon illusion." The newspaper at one meter provided a strong stimulus for reducing the perceived size of the projected moon. Conversely, the outside views of the campus buildings provided strong stimuli for increasing the perceived size of the projected moon. Figure 2 shows that changing the spatial distribution of background texture changes the apparent size of the moon.

From the third and fourth floor windows the moon was projected, respectively, onto the roof of a sorority house next to the Psychology building and the roof of the English building across the street. Little texture was visible beyond the rooftops in either view. From the third floor the moon was judged to be 12 percent larger than the moon on the newspaper at one meter. The view from the fourth floor, being of slightly higher elevation, showed a bit more distant texture, and accordingly, its apparent size was slightly greater than on the third floor.

From the fifth and sixth floors, the moon was projected just above the horizon. Tops of trees and taller buildings in the far distance were visible from the sixth floor but not from the fifth. This spatial distribution of texture caused the apparent size of the moon to increase. From the sixth floor, textural cues were plentiful all the way to the very distant horizon. On the seventh and eighth floors, the moon was projected against the sky higher and higher above the horizon, more and more like a zenith moon. It was surrounded by empty sky. All of the ground terrain was visible but not close to the moon, and distant texture began to take on a flatter appearance. Under these conditions, the apparent size of the moon decreased.

In summary, the fabled moon illusion has been quantitatively related to distances to visible texture, and the distance of accommodation is suggested

as the mediating oculomotor function. One can hypothesize that, as elevation increased from the third to the sixth floors, visual accommodation was drawn to ever increasing distances resulting in ever increasing apparent sizes of the moon. Conversely, as the distant visible texture dropped away from central vision, accommodation lapsed toward its resting distance, as it does when the moon is surrounded by empty sky rather than textured terrain. Thus, as indicated by this experiment, objects would be expected to appear smaller above a certain elevation as the moon moves away from the terrain,

RESULTS OF EXPERIMENT II

As in Experiment I, moon size ratios were again based on the apparent size of the moon projected onto the newspaper at one meter. Mean size ratios were 1.43 for All texture visible, 1.10 for Near, 1.13 for Intermediate, 1.22 for Far, 1.50 for Very Far, and 1.14 for No texture visible below the horizon (Figure 3). Differences in size judgments between mask conditions were reliable ($\underline{F}$ = 7.8, $\underline{df}$ = 5/25, $\underline{p}$ = .0002). As in Experiment I, these ratios are close to those expected from Kaufman and Rock's size ratios. Size judgment data show that presentation of successively more distant bands of background texture causes the apparent size of the moon to increase.

A second set of size ratios was based on the apparent size of the horizon moon with the "unmasked" background scene (clear-mask control condition) in which visible texture was not varied. Thus, ratios indicate how apparent size changes as different bands of texture are obscured relative to unrestricted vision. These ratios are not precisely comparable to those based on the sixth floor view from Experiment I because different groups of subjects were used. Obtained ratios were 0.70 when only the newspaper at one meter was visible, 0.77 when the mask revealed only Near texture, 0.79 for Intermediate texture, 0.86 for Far texture, 1.05 for Very Far texture, and 0.80 when No texture below the horizon was visible.

Finally, a third set of size ratios was based on the apparent size of the moon under the No-texture condition, similar to a zenith moon. Ratios then become 0.87 for the newspaper, 0.96 for the Near texture, and 0.99 for the Intermediate. For the Far, Very Far, and All-texture conditions, the apparent size of the moon was larger than it was with the mask approximating the zenith-moon condition; ratios were 1.08, 1.31, and 1.25, respectively.

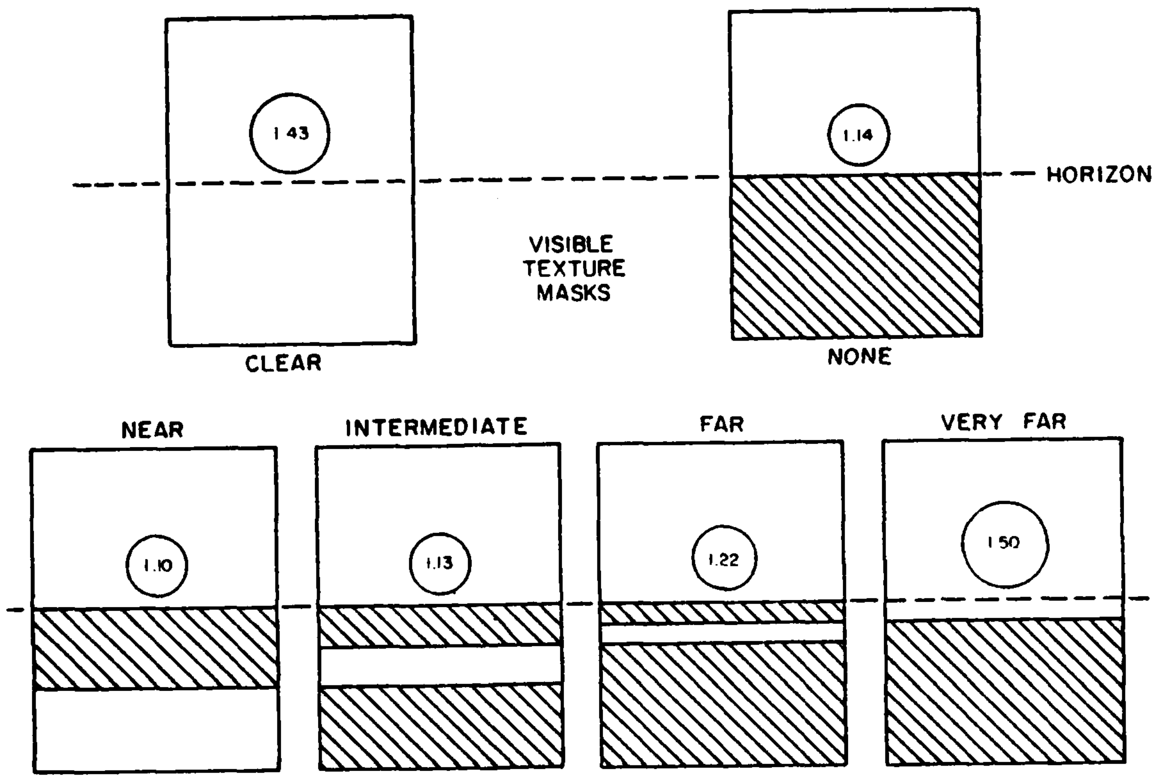

Figure 3. Apparent size of the moon when different horizontal bands of texture are visible from the center view on the sixth floor, expressed as a ratio of its size when projected onto a newspaper at one meter. The vertical dimensions of the bands of visible texture were approximately as follows: Very Far: from horizontal to -3°; Far: -3° to -6°; Intermediate: -6° to -12°: and Near: -12° to -22 1/2°.

Thus, viewing distant background stimuli resulted in larger apparent sizes of the moon than viewing no ground texture, and viewing close stimuli resulted in smaller apparent sizes.

Table 3 shows a comparison of the apparent size ratios using the different bases. Note that the ratio sets closely parallel one another. They represent three different ways of expressing the effect of texture on apparent size. When projected against any outside view, the moon appeared larger than when projected onto the newspaper at one meter; clearly the paper was a powerful stimulus to a small-sized moon. Conversely, with the Far, All-texture, and Very Far masks, its apparent size was successively larger than that observed when no texture was visible below the horizon, presumably an effect of drawing accommodation outward from its resting distance.

Accommodation values paralleled apparent size values with reliable mean differences ($\underline{F} = 12.6$, $\underline{df} = 5/25$, $p < .0001$). Mean accommodation in diopters was 0.09 for All texture visible, 0.74 for the newspaper, 0.49 for the Near mask, 0.28 for the Intermediate, 0.08 for Far, -0.27 for Very Far, and 0.36 for No texture visible. Presentation of successively more distant bands of background texture caused eyes to accommodate farther and farther from their resting distances. Note that Very Far texture pulled accommodation out even farther than complete visibility, with an associated increase in apparent size (Figure 3). Ascending and descending adjustments of the optometer did not result in different accommodation readings ($\underline{p} = .68$). Also, the interaction was not reliable.

After the reliability of mean differences was shown, the shifts in the size judgments and accommodation measures were considered for the Near, Intermedia.., Far, and Very Far textural bands, relative to the No-texture condition. Not only was the No-texture mask most comparable to a zenith moon; as evident

TABLE 3

Apparent Size of the "Moon" under Different Viewing Conditions Expressed Relative to (1) its "Size" when Projected onto a Newspaper at One Meter, (2) its "Size" with No Texture Visible Below the Horizon, and (3) its "Size" with All Texture Visible in the Center View from the Sixth Floor.

	RATIO BASE		
Mask	Newspaper	No Texture	All Texture
Newspaper	(1.00)	0.87	0.70
Near Texture	1.10	0.96	0.77
Intermediate	1.13	0.99	0.79
No Texture	1.14	(1.00)	0.80
Far Texture	1.22	1.08	0.86
Very Far	1.50	1.31	1.05
All Texture	1.43	1.25	(1.00)

TABLE 4

Apparent Size of the "Moon" in Degrees (Y_i) and Visual Accommodation in Diopters (X_i) for Each Subject Viewing, respectively, the Unobstructed Scene (All Texture), the Sky Only (No Texture), and the Collimated Moon Presented in Darkness; also, Accommodation to the Comparison Moon in Darkness and the Resting Accommodation (Dark Focus).

	VIEWING CONDITION							
	All Texture		No Texture		Collimated Moon		Comparison Moon	Dark Focus
Subject	Y_i	X_i	Y_i	X_i	Y_i	X_i	X_i	X_i
1	1.14	0.63	0.73	0.74	0.78	0.86	1.19	1.17
2	0.78	0.55	0.68	1.08	0.65	0.83	0.88	1.08
3	1.41	0.21	1.00	0.43	0.89	1.23	0.78	0.92
4	0.73	-0.24	0.67	0.03	0.67	-0.22	-0.05	0.07
5	0.92	-0.02	0.82	-0.09	0.91	-0.42	-0.36	-0.41
6	1.01	-0.61	0.89	-0.04	0.86	-0.61	-0.49	-0.56
$\overline{Y}$ $\overline{X}$	1.00	0.09	0.80	0.36	0.79	0.28	0.33	0.38

from Table 4, accommodation to it was highly correlated with the subjects' dark focus distances ($r = .90$, $p < .05$) and accommodation to the comparison moon ($r = .89$, $p < .05$). In addition, accommodation to the comparison moon correlated almost perfectly with dark focus ($r = .99$).

The shifts in apparent size and visual accommodation, shown in Tables 5 and 6 respectively, indicate great variability in both central tendency and range of responses among individuals. To equalize the variance, each individual's size and accommodation shifts were standardized as presented in Tables 7 and 8. Note that shifts in size judgments and accommodation for the All-texture mask and the newspaper from the No-texture base were not included here. Only considered were conditions in which the view was manipulated by masking particular bands of texture, namely the Near, Intermediate, Far, and Very Far mask conditions.

Standardization clarified the relationships among responses to the four masks. The correlation between standardized size and accommodation distances (the inverse of diopters) was .84 ($p < .001$) with an Eta coefficient of .93 ($p < .001$). Figure 4 shows this correlation; although the hypothesis of linearity is tenable for the limited data sample, a curvilinear relationship is apparent. The obtained F was 2.35, slightly below the 2.70 needed for rejection of linearity at $p = 0.05$. On the basis of the apparent curvilinearity of the relationship, a second-order transformation was applied to the Z-scores for apparent size, specifically, $\text{Size}' = 1.23\ \text{Size} - 0.47\ \text{Size}^2 + 0.47$. The correlation following this transformation rose to 0.89 with a $p < .0001$. The resulting scatter plot, shown in Figure 5, appears linear.

TABLE 5

Shifts in Apparent Size of the "Moon" in Degrees Relative to the No-Texture Condition when Different Textural Bands Were Visible.

	VISIBLE TEXTURAL BAND					
Subject	Near	Inter-mediate	Far	Very Far	$\bar{Y}$ Subject	σ_Y Subject
1	-.03	-.02	+.12	+.33	+.10	.14
2	-.04	-.02	+.02	+.10	+.02	.05
3	-.08	-0.8	+.05	+.55	+.11	.26
4	+.02	+.04	+.11	+.05	+.05	.03
5	-.01	+.01	+.01	+.06	+.02	.03
6	-.02	+.01	+.05	+.18	+.06	.08
$\bar{Y}_{MASK}$	-.03	-.01	+.06	+.21		

TABLE 6

Shifts in Visual Accommodation in Diopters Relative to the No-Texture Condition when Different Textural Bands Were Visible.

	VISIBLE TEXTURAL BAND					
Subject	Near	Inter-mediate	Far	Very Far	$\bar{X}$ Subject	σ_X Subject
1	+.03	+.14	-.12	-.36	-.08	.19
2	-.33	-.40	-.43	-.79	-.49	.18
3	+.39	+.36	-.09	-.54	+.03	.38
4	+.16	-.19	-.39	-.19	-.15	.20
5	+.48	+.07	-.32	-.36	-.03	.34
6	+.05	-.42	-.34	-.40	-.28	.19
$\bar{X}_{MASK}$	+.13	-.07	-.28	-.44		

TABLE 7

Shifts in the Apparent Size of the "Moon" for Each Subject when Different Textural Bands Were Visible Relative to the No-Texture Condition, Expressed as Z-Scores. Z-Scores Based on Each Subject's Own Standard Deviation among Shifts in Apparent Size for Each of the Four Textural Bands.

	VISIBLE TEXTURAL BAND			
Subject	Near	Intermediate	Far	Very Far
1	-0.90	-0.81	+0.13	+1.59
2	-1.01	-0.62	+0.03	+1.61
3	-0.73	-0.74	-0.23	+1.70
4	-1.00	-0.47	+1.66	-0.19
5	-0.97	-0.25	-0.44	+1.67
6	-0.98	-0.55	-0.12	+1.65
$\overline{Z}_y$	-0.93	-0.57	+0.17	+1.34

TABLE 8

Shifts in Accommodation Distance when Different Textural Bands Were Visible Relative to the No-Texture Condition, Expressed as Z-Scores. Z-Scores Based on Each Subject's Own Standard Deviation among Shifts in Accommodation for Each of the Four Textural Bands.

	VISIBLE TEXTURAL BAND			
Subject	Near	Intermediate	Far	Very Far
1	-0.58	-1.16	0.25	1.50
2	-0.91	-0.48	-0.30	1.69
3	-0.95	-0.87	0.32	1.50
4	-1.57	0.18	1.21	0.18
5	-1.51	-0.30	0.84	0.96
6	-1.71	0.73	0.33	0.65
$\overline{Z}_x$	-1.20	-0.32	0.44	1.08

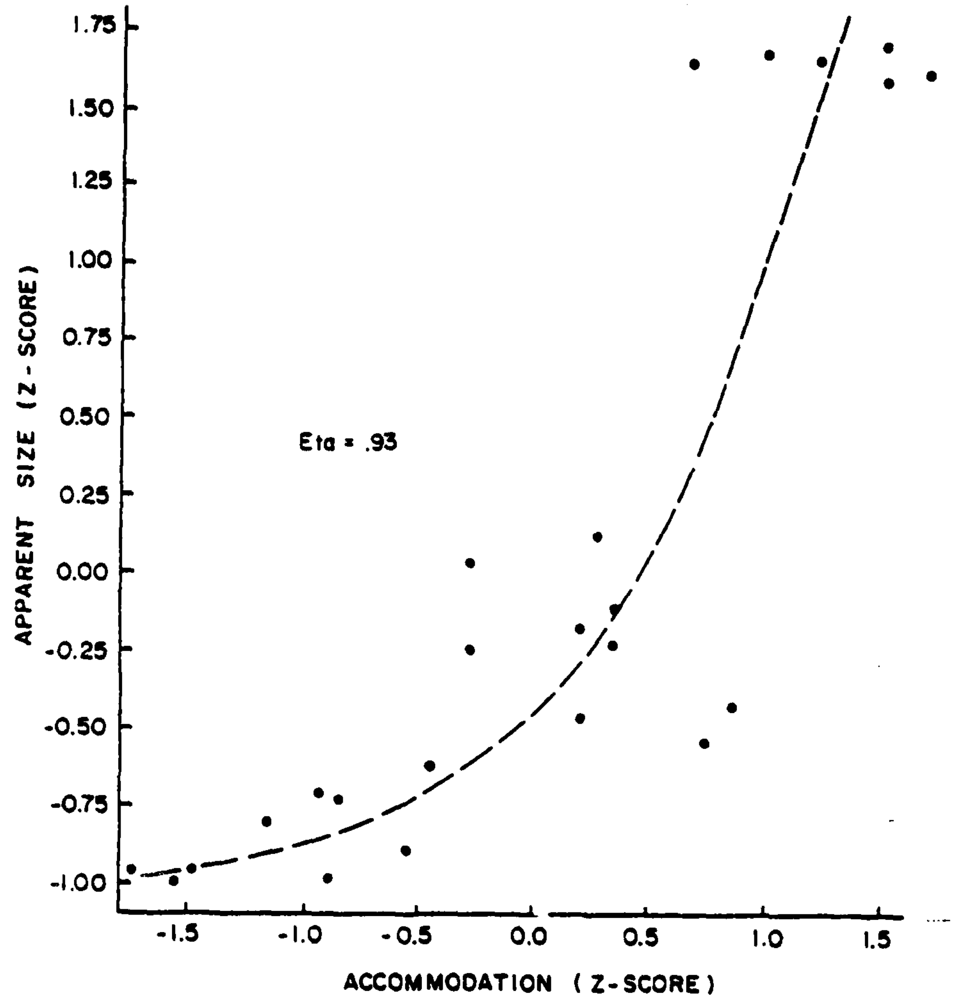

Figure 4. Scatter plot of the relationship between apparent size and visual accommodation distance, both variables expressed as Z-scores based on each subject's own standard deviation among textural conditions, as listed in Tables 7 and 8.

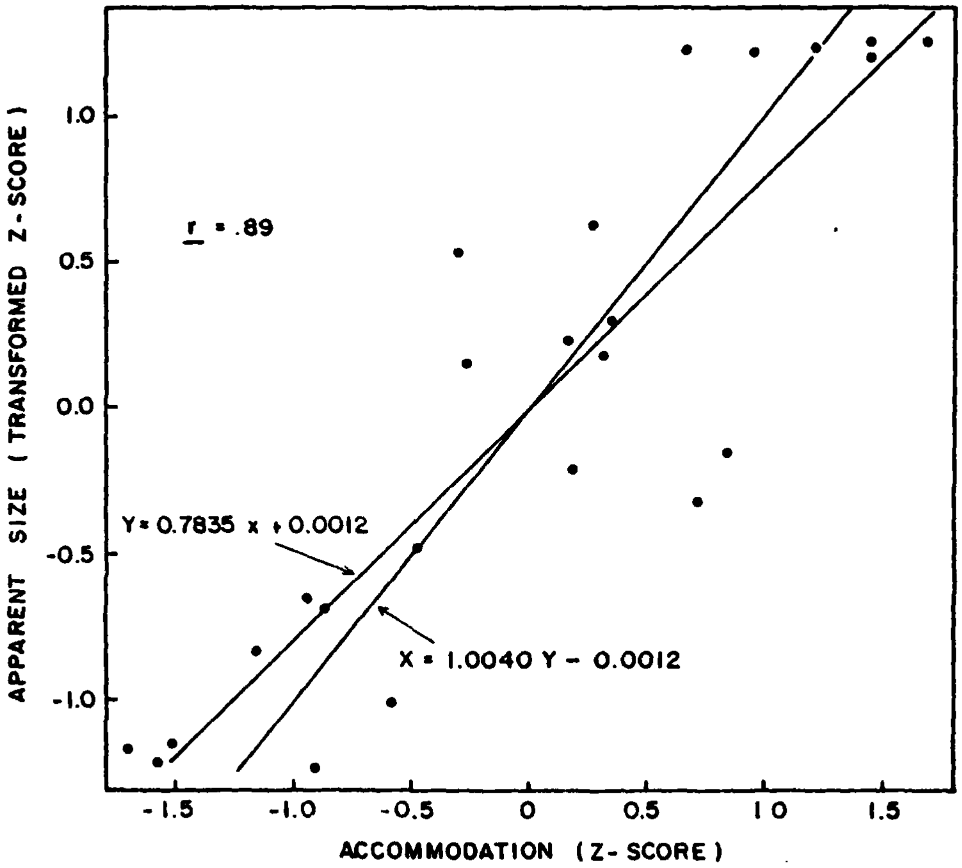

Figure 5. Scatter plot of the relationship between apparent size, expressed as a transformed Z-score (specifically, 1.23 Size - 0.47 $Size^2$ + 0.47), and visual accommodation distance, expressed as a Z-score.

DISCUSSION OF EXPERIMENT II

The distance-of-accommodation hypothesis is further supported by Experiment II. Viewing the newspaper at one meter yielded the smallest apparent size of the moon. Presentation of Near or Intermediate texture increased apparent size but not as much as presentation of All texture, Far, or Very Far texture. Similarly, the newspaper acted as the strongest near accommodation "trap," and presentation of successively more distant bands of texture pulled accommodation outward.

In fact, Very Far texture acted as a stronger accommodation stimulus and resulted in a slightly though unreliably larger apparent moon size than did unmasked visibility. This result is in line with a distance-of-accommodation explanation of premature landings on approaches over water at night toward an airport with a background of city lights. When only distant texture is visible, pulling accommodation outward, visible objects appear larger and nearer and expanded downward in the visual field. Thus, the pilot could drop below the proper flight path and unexpectedly land in the water short of the runway.

On the other hand, the mere obscuring of the small band of texture visible in the Very Far mask, so that no texture below the horizon could be seen, markedly decreased the apparent size of the moon, and the distance of accommodation, to values almost as small as those when the moon was projected onto the newspaper at one meter. The effect of obscuring all texture below the horizon is similar to viewing the moon overhead. Accommodation tends to lapse toward its dark focus when no resolvable background texture is present.

As successive bands of texture were presented, size judgments and accommodation distances concurrently increased; an Eta coefficient of .93 indicates a strong relationship. The product moment correlation of .83 suggests that the relationship, though strong, is not necessarily linear.

Furthermore, inclusion of a quadratic component in the equation increases the correlation to .89. In other words, apparent size is related to accommodation distance in accordance with a function that represents a compromise between the diameter and the area of a disc. Presumably an analogous relationship would hold for objects of other shapes, such as squares, triangles, trapezoids, and airport runway outlines.

One additional point demonstrated by the data is that distant stimuli were relatively more powerful accommodation "traps" than near peripheral stimuli. Some inhibition of far accommodation responses may have occurred because of the vaguely visible close texture afforded by the edges of the masks and the surface of the combining glass, but the inhibition was not sufficient to negate the differential attraction of different distant views. If near peripheral texture had no stimulus value, one might expect a greater range of dynamic accommodation responses than was actually observed.

This experiment demonstrated that visual accommodation and the apparent size of objects continue to covary well beyond the nominal distance of optical infinity. The prevailing concept of accommodation is that it is a unidirectional process that ranges only inward from zero diopter toward higher dioptric levels to maintain a focused image on the retina. However, the present results indicate that there is a large range of oculomotor adjustments beyond the distance at which the entire visual scene appears to be in clear focus. Such adjustments may partially account for the phenomenal experience of size constancy, and, in the absence of adequate textural cues to objective distance, may produce bias errors in the apparent size and angular position of distant objects.

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